High Precision Mass Measurements in Ψ and Υ Families Revisited

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Abstract

High precision mass measurements in Ψ and Υ families performed in 1980-1984 at the VEPP-4 collider with OLYA and MD-1 detectors are revisited. The corrections for the new value of the electron mass are presented. The effect of the updated radiative corrections has been calculated for the $J/\Psi(1S)$ and $\Psi(2S)$ mass measurements.

Development of the resonant depolarization method (RDM) suggested in Novosibirsk [1, 2] opened unique opportunities in the high precision determination of the elementary particle masses. Pioneer experiments in Novosibirsk (see [3] and references therein) were

followed by those at Cornell [4], DESY [5] and CERN [6]. In this paper we reconsider our measurements performed at the e^+e^- collider VEPP-4 in Novosibirsk in the Ψ [7, 8] and Υ meson families [9, 10, 11, 12, 13] with the goal to take into account the change of the electron mass value [14, 15] as well as the updated radiative corrections [16] in case of $J/\Psi(1S)$ and $\Psi(2S)$.

$J/\Psi(1S)$ and $\Psi(2S)$ mass measurements [7, 8] were performed in 1980 with the OLYA detector [17] while the MD-1 group [18] carried out three independent measurements of the $\Upsilon(1S)$ mass in 1982 [9], in 1983 [10] and in 1984 [11, 12] as well as determined the masses of $\Upsilon(2S)$ and $\Upsilon(3S)$ in 1983 [10, 13]. The masses of the Ψ and Υ mesons were obtained from a fit of the energy dependence of $\sigma(e^+e^- \to hadrons)$ and relating the value of the resonance mass to the beam energy. The absolute calibration of the beam energy was performed using the RDM.

The resonant depolarization method is based upon the fact that in a storage ring with a planar orbit the spin precession frequency Ω_s depends on the beam energy E as

$$\Omega_s = \omega(1 + \frac{\mu'}{\mu_0}\gamma), \tag{1}$$

where ω is the beam revolution frequency, μ'/μ_0 is the ratio of the anomalous and normal parts of the electron magnetic moment, $\gamma = E/mc^2$ is the Lorentz factor of electrons. The frequency Ω_s is measured at the polarized electron beam using a depolarizer with the frequency Ω_d adjusted as $\Omega_d = \Omega_s + n\omega$, where n is an arbitrary integer number.

A typical accuracy of the method is about 10^{-5}. However, the measured quantity is a γ factor of electrons rather than their energy. Thus, the beam energy and the resonance mass determined by the RDM depend on the electron mass assumed. In 1986 when the results of the $\Upsilon(1S)$ mass measurement were published [11], its accuracy was about five times worse than the claimed accuracy of the electron mass in the MeV scale (2.8 *ppm*) [14]. However, in "The 1986 adjustment of the fundamental physical constants" [15] the value of the electron mass was decreased by 8.5 *ppm* while its error was reduced to 0.3 *ppm*.

The decrease of the electron mass [15] was caused mainly by the 7.8 *ppm* (about three "old" standard deviations) increase of the e/h ratio. Taking into account that two other fundamental constants which depend on e, h and m_e, i.e. the fine-structure constant α and Rydberg constant R_∞, remained almost unchanged, the increase of e/h propagates to the abovementioned 8.5 *ppm* decrease of m_e in the MeV scale. Since resonance masses determined from RDM are based upon the value of the electron mass and are quoted in MeV, they should be also decreased by 8.5 *ppm*. The corresponding corrections to the values of the $\Upsilon(1S), \Upsilon(2S)$ and $\Upsilon(3S)$ meson masses measured by MD-1 were already reported at the Chicago Conference [19].

An additional correction should be applied to the values of the $J/\Psi(1S)$ and $\Psi(2S)$ mass obtained in [7, 8]. Similarly to most early measurements, a fit of $\sigma(e^+e^- \to hadrons)$ in these papers included the radiative corrections calculated according to the classic work of Jackson and Scharre [20]. Later, in Ref. [16] it was shown that the approach of Ref. [20] is not quite accurate and, in particular, violates the Bloch-Nordsieck theorem. Correspondingly, the analysis of the Υ resonances was performed [11, 12, 13] using the improved radiative corrections suggested in [16]. In Ref. [11] it was shown that the corresponding shift of the mass was about 0.1 MeV. Somewhat later the paper [21] was published entirely dedicated to the correction of the old measurements of Ψ and Υ parameters using the updated radiative corrections. However, the $J/\Psi(1S)$ and $\Psi(2S)$ masses were neither refit by the authors of Ref.[7, 8] nor quoted in Ref.[21].

The details of $J/\Psi(1S)$ and $\Psi(2S)$ mass measurements [7, 8] are not available now. Therefore, the $J/\Psi(1S)$ and $\Psi(2S)$ mass corrections were estimated by us as in Ref.[21] from the difference of the fits with the radiative corrections from Ref.[20] and Ref.[16]. Similarly to Ref.[20], only the electron loop was taken into account in the photon vacuum polarization term in Ref.[7, 8]. The resulting mass correction for radiative effects equals -$(0.023\pm0.003)\sigma_w$, where σ_w is the rms spread of the e^+e^- center of mass energy and the error accounts for dependence of the correction on the luminosity distribution around the resonance. The correction is somewhat lower than that which can be obtained from Fig.6 of Ref.[21]. At $\sigma_w = 0.7(1.0)$ MeV in $J/\Psi(1S)$ and $\Psi(2S)$ runs it equals -0.016 MeV and -0.023 MeV respectively.

Table 1 presents a list of the resonance masses measured at the VEPP-4 collider with the corresponding corrections, where $\Delta M(m_e)$ and $\Delta M(rad.)$ stand for the correction for the electron mass and radiative effects respectively.

Let us briefly discuss how the change of the resonance masses above can affect other measurements. The new value of the $\psi(2S)$ mass should be taken into account during the interpretation of the Fermilab studies of the charmonium family in $p\bar{p}$ annihilation [22] which used the value of the $\psi(2S)$ mass from [7, 8] as a basic calibration in their determination of the $J/\psi(1S)$ mass. It is obvious that the obtained values of the m_e correction for $\Upsilon(1S)$ and $\Upsilon(2S)$ can also be applied to the Cornell [4] and DESY [5] measurements respectively. Since in these experiments the radiative corrections were calculated according to Ref.[20], their results should be also corrected for the radiative effects. We remind that our value of the $\Upsilon(1S)$ mass differs by more than 3.5 standard deviations from that at Cornell while for $\Upsilon(2S)$ it is consistent with the one in DESY. Our measurement of the $\Upsilon(3S)$ mass has not been repeated by any other group.

Table 1: Revision of mass measurements in Ψ and Υ families

Particle	**Previous mass, MeV**	$\Delta M(m_e)$, **MeV**	$\Delta M(rad.)$, **MeV**	**Updated mass, MeV**
$J/\Psi(1S)$ [7, 8]	3096.93±0.09	-0.026	-0.016	3096.89±0.09
$\Psi(2S)$ [7, 8]	3686.00±0.10	-0.031	-0.023	3685.95±0.10
$\Upsilon(1S)$ [12]	9460.59±0.09±0.05	-0.080	-	9460.51±0.09±0.05
$\Upsilon(2S)$ [10, 13]	10023.6±0.5	-0.085	-	10023.5±0.5
$\Upsilon(3S)$ [10, 13]	10355.3±0.5	-0.088	-	10355.2±0.5

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